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A New Wave in Engineering Education: Understanding the Beat of Active Learning through Innovative Tutorial Assessment

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A New Wave in Engineering Education: Understanding the Beat of Active Learning through Innovative Tutorial Assessment

by

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Abstract

A New Wave in Engineering Education: Understanding the Beat of Active Learning through Innovative Tutorial Assessment

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Recent efforts in engineering education research have set in motion reform advocating more active learning in the classroom. Active learning centers on the student and consists of pedagogical approaches to address the broad spectrum of educational backgrounds and demographics. In order to further the research focused on active learning products, appropriate and innovative assessment methods must be developed. For this thesis, innovative active learning modules are the focus of the analysis. In total, 12 Finite Element tutorials are designed and assessed using both statistical analysis and confidence interval correlations. Fundamental and informative assessment strategies have been developed to iteratively improve active learning approaches. Results of this process show that the finite element tutorials lead to enhanced student learning that can span across student demographics. Certain cases do exist where unique learning styles or personality types respond more positively to this pedagogical technique than others. Global outcomes are presented to assess these tutorials cumulatively, as active learning products. Finally, the assessment methodology is redesigned into a useful toolkit for educators to follow in furthering efforts of integrating active learning into any engineering classroom.

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CHAPTER 1. INTRODUCTION

1.1 MOTIVATION

The purpose of active learning is to solicit participation by students beyond the passive mode of classroom lectures. Reading, writing, participating in discussions, hands-on activities, engaging in active problem solving and collaborative learning can all be involved. The skills acquired during active learning tend to go above and beyond basic comprehension of a lesson. In fact, the goal of active learning is to not only enable student comprehension, but also to assist the student in cultivating valuable aptitudes for synthesizing, analyzing, and evaluating ideas and their learning experiences. This captures a significantly larger portion of learning comprehension than would be available in a lecture-only situation.

One model for active learning comes to us in the form of tutorials, or active learning modules, aimed at improving student learning in historically difficult subject areas in engineering through the use of finite element analysis. The tutorial set developed here includes learning modules for various subject areas in Mechanical, Electrical, and Biomedical Engineering courses.

As part of this research work, more fundamental and informative assessment strategies have been developed for active learning products. The intent of this extended assessment process is to discover potential inequities across a range of demographic and student-learning variables. In particular, pre- and post-quiz scores are correlated with demographic and student-learning variables. Statistical analysis determines whether certain student groups benefit more from the learning modules than other groups. Results of this process show that, overall, the finite element tutorials lead to enhanced student learning that can span across student demographics. Certain cases do exist where unique learning styles or personality types respond more positively to this pedagogical technique than others. The opportunity for iterative feedback will lead to subsequent improvements. The most important, and contributory, result is an exciting new algorithm to perform this type of assessment across active learning approaches.

The aim of this study is to determine if tutorials of this type are in fact effective active learning tools. In each participating course, after the student completes their traditional lecture series, they are introduced to a computer-based tutorial. In order to perform a baseline study, students are administered the same content quiz before and after the tutorial. These quiz results are statistically analyzed to determine if comprehension is improved because of the tutorials. With a novel Equitability Correlation Assessment Methodology (ECAM), we are able to judge if these tutorials afford all students with an equitable active learning experience. The innovative approach is to integrate learning styles and personality types for this equitability assessment. The active learning modules prove to be an exciting step towards improving comprehension of challenging engineering content in an active learning environment.

1.2 RESEARCH OBJECTIVES AND HYPOTHESIS

As educators move forward in advancing engineering education, active learning tools are a viable choice for addressing how students struggle with complex topics in engineering, especially as a function of their backgrounds, demographics, and personality types. In the quest to introduce active learning methods to the classroom, these particular methods must be designed, implemented, and assessed properly. On a whole, these pedagogical techniques have not yet been fully developed in engineering curriculum, especially within core courses (Wankat and Oreovicz 1993; Wood, Jensen et al. 2001; Jensen, Rhymer et al. 2002). In order to move beyond the typical road bumps encountered when teaching difficult application methods, contemporary methods are being developed that seek to engage students actively, inside and outside the classroom, as well as kinesthetically through the varied human senses. Such active learning approaches have the potential to improve student comprehension and knowledge retention, and, most importantly, to increase students' interest in the material (Linsey, Talley et al. 2007).

Assisting students in the learning of imperative analysis tools is especially vital for the current techniques used in industry. One such technique is finite element analysis. The finite element (FE) method is widely used to analyze engineering problems in commercial engineering firms. It is an essential and powerful analytical tool in designing products with ever-shorter development cycles (Mahoney 1999; Thilmany 2000; Thilmany 2001). In the past, consulting firms needed Ph.D. and M.S. engineering graduates to analyze designs with FE, but recently these firms are asking their B.S. and A.A.S. engineering graduates to learn and apply this complex analysis technique (Thilmany 2000; Thilmany 2001). In many undergraduate programs, the FE method is not taught as a required element, and graduates often lack knowledge of the proper use of this tool (Belytschko, Bayliss et al. 1997; Brinson, Belytschko et al. 1997). Two principle reasons for this are:

1. Introducing new material in curricula typically requires the removal of other material (possibly essential material as considered by the faculty and ABET). This approach must be balanced with the recent push to reduce total credit hours of programs nationwide.
2. FE coursework is typically organized around theoretical details considered more appropriate for graduate students who may have a more rigorous mathematical education than undergraduate students.

The basic FE method is currently offered as an introductory elective senior project course in mechanical, civil, and aeronautical engineering programs (Chiou 1998; Milton-Benoit, Grosse et al. 1998; Matthews and Jahanian 1999; Rencis, Kwok et al. 1999; Graham 2002). However, more effective instructional methods may be available to a broader spectrum of students if FE analysis is sequentially integrated throughout required engineering courses (Nesbit 1994; Sorby, Walker et al. 1999; Baker, Capece et al. 2001). For example, the University of Texas at Austin's Mechanical Engineering senior capstone project often requires students to perform FE analysis of designed systems. To meet that objective, students have to learn the method on their own unless they are enrolled in elective Computer Aided Design courses that touch on one or two FE commercial software packages.

An important goal of this work is to educate a diverse set of undergraduate engineering students with a basic knowledge of FE theory, along with practical experience in applying commercial FE software to engineering problems. The lack of experience in using numerical computational methods in designing structural solutions is a noted problem for some engineering graduates (Belytschko, Bayliss et al. 1997; Brinson, Belytschko et al. 1997). The Accreditation Board for Engineering and Technology (ABET) expects engineering graduates to have: "an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice" (ABET 2006) such as FE analysis. Higher-education institutions are planning to add FE analysis to their curriculum (Nesbit 1994; Chiou 1998; Matthews and Jahanian 1999; Sorby, Walker et al. 1999; Baker, Capece et al. 2001; Graham 2002), but this plan is not evolving quickly enough to meet the demand of firms competing in the global economy. To support schools in their teaching efforts, the finite element exercises developed in this work provide a valuable, web-based resource to engineering instructors throughout the world.

An NSF funded Course, Curriculum, and Lab Improvement (CCLI) proof-of-concept project that corresponds with this work aims at developing FE tutorials. These learning modules can be easily implemented in "traditional" undergraduate engineering courses. The FE learning modules provide students with hands-on experience in FE method applications in problem modeling. The models include problem definition, project educational objectives, analysis approach, assumptions, goals, and comparison to hand calculations or experimental data, following a unique learning cycle known as Kolb's Cycle (Kolb 1984). To enhance learning for those unfamiliar with the commercial FE software, students are provided with systematic, step-by-step procedures of modeling.

Initially, FE learning modules in six engineering areas: (1) structural analysis, (2) mechanical vibrations, (3) fluid mechanics, (4) heat transfer, (5) electromagnetics, and (6) biometrics were developed. These modules are integrated into existing courses in the corresponding engineering subject areas for evaluation. Faculty and students initially assessed the effectiveness of the modules at three higher educational institutions. The project team is composed of experienced and well-qualified engineering educators at these institutions along with an engineering educator and independent evaluators at three other higher-education institutions.

The independent evaluators develop the project assessment goals, as they relate to the learning objectives. To analyze the effectiveness of the FE tutorials, a level of improved understanding is calculated by relating quiz scores to learning styles and personality types, followed by the application of basic statistical analysis. The end goal is to accurately and comprehensively assess the quality of the learning modules and whether they are equally serving students across different factors. These assessment goals will be accomplished through three project assessment objectives:

1. *Assessment Methodology*. Develop, implement iterative assessment system.
2. *Statistical Measures*. Determine improvement, if any, in student learning across various student groups or distributions.
3. *Equitability Study*. Gain insight into the effectiveness of the FE learning modules across various personality types and learning styles.

Overall, there are several specific and general hypotheses to be made about the research efforts. Specifically, I predict that improvement to student learning will be evident across selected tutorial use. In addition, I believe that efforts to develop the assessment method will be introductory, and flexibility will be the key to further development and use of such an assessment methodology. Finally, after my search into the literature and history of research in the field, it will be clear that this work is an important step forward in the active learning process. In general, my propositions for this work are threefold:

1. The results of such a large-scale effort will present numerous feedback mechanisms to improve future iterations on this project,
2. The assessment methodologies considered will be combined into a novel hybrid methodology to further the combined efforts of enhancing education and reaching students equally, and
3. The concept of active learning will prove to be an effective tool in furthering the field of engineering, especially in regards to difficult curriculum like finite element analysis.

With these lofty research goals and hypotheses in mind, we can move forward with the overall thesis roadmap before heading into our background research concepts.

1.3 Thesis Organization

Chapter 2. Background: An Active Learning Context

Chapter 2 presents previous, current, and on-going work in the area of engineering education. This includes the specific research focused on active learning and educational assessment methodologies. A complete literature review dives into the background work on learning styles indices. This section also discusses how our work fits into the big picture of engineering education and what we have learned from our contemporaries.

Chapter 3. Research Framework

Chapter 3 starts with the background work on designing and developing these finite element tutorials with active learning foundations. The basic steps taken to develop each of the 12 FE tutorials are modeled using an exemplary tutorial. Subject matter and problem scenario selection are presented. Then we dive deeper into the creation and assessment of the tutorials. Further discussed are the analytical tools to perform this design based, baseline study.

Chapter 4: Equitability Correlation Assessment Method

Chapter 4 presents our innovative assessment algorithm for determining how well the tutorials are reaching all students. The development of this unique educational tool discusses the foundations and results of our experimental assessment algorithm. The Equitability Correlation Assessment Method (ECAM) can be used as a tool with any useful demographic for assessment measurement. The goal of this assessment method is to ensure all student learning is being enhanced equitably.

Chapter 5: Analysis and Results

Chapter 5 presents the tutorial specific as well as the global results of our study. From this multifaceted analysis, conclusions are made about the efficacy of the finite element tutorials on an individual and cumulative basis. The global results are analyzed in particular for the tutorial effectiveness as active learning tools.

Chapter 6: Discussion and Invention

Chapter 6 opens up an overall discussion of the tutorial performance and what we have learned from this work. First, the ECAM work is discussed before we focus on the active learning tutorials in general. This chapter also represents the tool that can be added to every engineering educator's toolbox as a result of this work. This step-by-step roadmap is an exciting step in the right direction towards improving our students' experience in the classroom to be a more active one.

Chapter 7: Conclusion and Future Work

Chapter 7 provides a closing to the research conducted for this thesis and possible areas for future work. The primary contributions to the field include the novel assessment methodology, opportunistic active learning results, and a guided roadmap invention. The final points of concern are brought to light and important findings are concluded.

Chapter 2. Background: An Active Learning Context

2.1 Pedagogical Foundations

By considering several unique pedagogies in the development of the FE tutorials, we may accomplish more than with any single contribution. This work draws on concepts from various sources including Bloom's Taxonomy, the Kolb Learning Cycle, Felder-Soloman Learning Styles, and Myers Briggs Type Indicator. While none of these tools are original to this work, combining their foundations to approach active learning techniques from a comprehensive viewpoint is innovative and useful. By continuously adapting these theories into combined active learning products, we are able to balance that learning process on accepted learning foundations and innovative new ones. The following sections discuss these foundational concepts that help us understand tutorial development and assessment.

2.1.1 Bloom's Taxonomy

Bloom's Taxonomy (Bloom 1956) helps us understand the logical levels of learning, with the first level being the most basic. With the building of knowledge up to the sixth and highest level, learning becomes more advanced. The six levels include knowledge, comprehension, application, analysis, synthesis, and evaluation. This particular pedagogy can assist instructors in building their foundations for learning from the ground up. It is just as important to traverse through the lower three levels thoroughly because they are essential to the upper three levels. Typical inefficiencies with text and lecture base courses include skipping straight from level 1 (theory) to level 3 (homework/exams) without providing students a chance for further explanation (level 2) that help validate assumptions. This problem persists when expecting students to be able to use proper assumptions in their design courses (level 5). Another common issue is with the failure to even reach level 5 or 6 in most courses, when these are highly regarded and expected of graduates. Both of these deficiencies are addressed in the creation of our active learning modules. The goal is to provide examples of all six levels in each FE tutorial, as seen in Table 2.1, adapted from (Bloom 1956).

Table 2.1: Bloom's Taxonomy Learning Levels

Level	Name: Description
1	Knowledge: List or recite
2	Comprehension: Explain or paraphrase
3	Application: Calculate, solve, determine or apply
4	Analysis: Compare, contrast, classify, categorize, derive, model
5	Synthesis: Create, invent, predict, construct, design, imagine, improve, produce, propose
6	Evaluation: Judge, select, decide, criique, justify, verify, debate, assess, recommend

From these six levels of learning, we can begin to investigate how an instructor could use the levels in developing curriculum and instruction. The following Bloom's Wheel [Figure 2.1] provides many examples of how to incorporate each level of learning in classroom activities.

Figure 2.1: Bloom's Wheel (adapted from Bloom's Taxonomy)

This instructing tool provides numerous examples of possible learning opportunities, many of which are only achievable through active learning.

2.1.2 Kolb Learning Cycle

The pedagogical foundations for this project are also based upon the Kolb Learning Cycle (Kolb 1984; Stice 1987; Brown 2004; Brown 2004). The Kolb model adapted in [Figure 2.2] describes a cycle around which learning experiences progress and include major steps like: concrete experience, reflective observation, abstract hypothesis and conceptualization, as well as active experimentation (Kolb 1984). The Kolb Learning Cycle improves student retention of the complex numerical procedure involved in FE analysis, in addition to the fundamental and difficult topical content of the subject areas. During courses integrating FE learning modules, students are introduced to FE theory within their traditional lectures. Instructors cover background of the FE method, fundamental mathematics of FE, the topology of the various finite elements, error analysis of FE results, and how to model engineering problems using this technique. Portions of Kolb's cycle are interlaced with hands-on activities that begin stating the proposed problem in a real-world manner. FE learning modules provide specific instructions on how to build the FE model of the engineering problem to increase student performance in the analysis for "Concrete Experience" on Kolb's cycle.

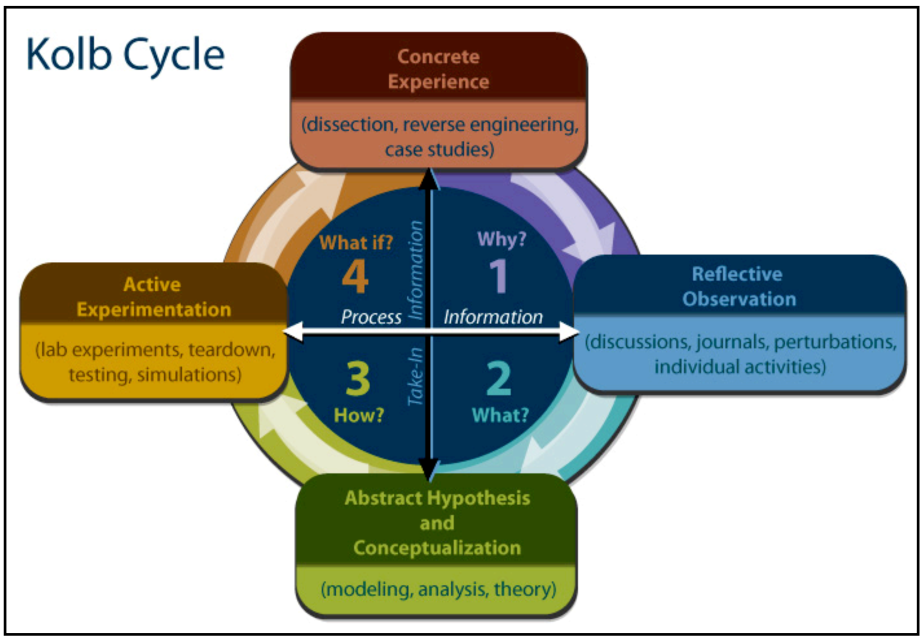


Figure 2.2: Kolb Learning Cycle Model

Research shows the ways in which each step improves retention of subject matter: 20% retention when only abstract conceptualization is used; 50% with reflective observation and abstract conceptualization; 70% with concrete experience, reflective observation and abstract conceptualization; and 90% with all four stages (Stice 1987).

2.1.3 Learning Styles

Each FE learning module was designed to span a spectrum of different characteristics in which students learn. The Felder-Soloman Index of Learning Styles (Felder 1988) is composed of four dimensions: active/reflective, sensing/intuitive, visual/verbal, and sequential/global, seen in Table 2.2. These dimensions represent students' preferences or aptitudes for learning. For example, some students prefer to learn visually, instead of verbally, while others have the aptitude for intuitive learning without even realizing this. An active learner may prefer to be very hands-on in their learning. They may have realized they learn better this way, or they may just have a subconscious tendency to be very active. What is important to note though, is active learning tools are not just geared towards active learners. This is a coincidental misnomer. One of the objectives of active learning tool design is to meet the needs of students with a range of learning styles. Particular approaches to teaching often favor a certain learning preference. Therefore it is important to incorporate a variety of teaching approaches, and active learning tools aid in this endeavor.

Table 2.2: Learning Styles Categories

Felder-Soloman	
ACTIVE	**REFLECTIVE**
Doing something active with it. Discussing, applying, or explaining it to others.	Thinking about it quietly first.
SENSING	**INTUITIVE**
Learning facts.	Discovering possibilities and relationships.
VISUAL	**VERBAL**
See-- pictures, diagrams, flow charts, time lines, films, and demonstrations.	Words-- written and spoken explanations.
SEQUENTIAL	**GLOBAL**
Gain understanding in linear steps.	Learn in large jumps, suddenly "getting it."

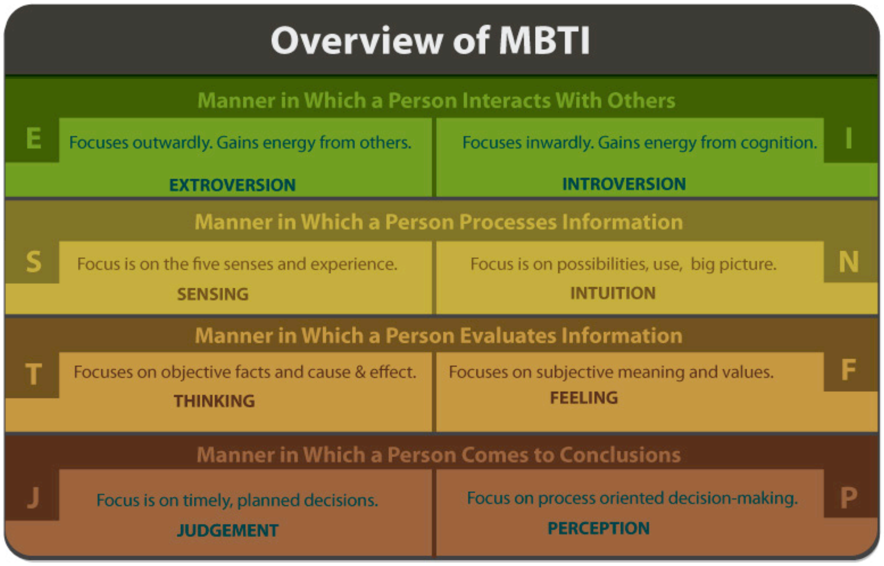
Every student, and individual for that matter, has a quadruple set of learning styles using the four pairs of indices. An example of a student's learning style is: Active, Intuitive, Visual, and Global. Just as there are many facets and combinations to a single student's learning preferences and capabilities, there can be many facets and combinations to a professor's teaching methods. This index, along with active learning pedagogy can assist instructors in creating learning modules that impact all student learning styles effectively.

2.1.4 MYERS BRIGGS TYPE INDICATOR PERSONALITY PREFERENCES

The Myers Briggs Type Indicator (MBTI) is similar to Felder-Silverman Learning Style, but is linked to personality preferences, as seen in Table 2.3. MBTI includes four categories of how an individual processes and evaluates information (Myers and McCaulley 1985). The first category describes how a person interacts with his or her environment. People who take initiative and gain energy from interactions are known as Extroverts (E). Introverts (I), on the other hand prefer more of a relatively passive role and gain energy internally. The second category describes how a person processes information. People who process data with their senses are referred to as Sensors (S), and persons who visualize where data is proceeding in the future are called an iNtuitors (N). The Sensor versus iNtuitor category is an interesting area of study when it comes to engineering education, because professors are historically intuitors while most engineering students are sensors (Felder and Silverman 1988). The third category for MBTI preference describes the manner in which a person evaluates information. Those who tend to use a logical cause and effect strategy, Thinkers (T), differ from those who use a hierarchy based on values or the manner in which an idea is communicated, Feelers (F). The final category indicates how a person makes decisions or comes to conclusions. Perceivers (P) prefer to be sure all the data is thoroughly considered, and Judgers (J) summarize the situation as it presently stands and make decisions more quickly.

Similar to the learning style index, each individual has a set of four letters that represent their unique MBTI type. For example, an individual reporting ENFJ is an extroverted, intuitive, feeler, judger. As one might imagine, considering all the possibilities that an individual could potentially report as their MBTI is complicated, as these paired facets can interact in interesting manners. But by splitting the many facets of personality into four pairs, we have greater understanding of how we can use this information when it comes to teacher-instructor relationships as well as curriculum building. Instructors can choose to consider MBTI data when forming student groups, or reflecting on their teaching methods.

Table 2.3: Myers Briggs Type Indicator Personality Preferences



A number of researchers have used knowledge of MBTI types to enhance engineering education (Kolb 1984; Stice 1987; Borchert, Jensen et al. 1999; Bowe, Jensen et al. 2000). In this prior educational research, it is shown that different MBTI types respond in unique ways to distinctive pedagogical approaches. The goal of using the MBTI data in concurrence with learning modules is to ensure the FE tutorials are effective across different personality types, bringing any of these nuances to light. The innovative step to our analysis here is to take the assessment one step beyond effectiveness. We are looking into how equitably this effectiveness reaches across demographic groups, learning styles, and personality.

2.2 Literature Review

Research in engineering education over the past few decades shows a general call for reform. Though considerable strides have been made in terms of adapting traditional teaching methods to meet the needs of new student generations, understandable voids still exist. Throughout this section, we discuss where the research has been focused in improving engineering education. This review involves studying and analyzing active learning tools and techniques, along with the assessment methods for determining their efficacy. If our interest in engineering education research is to remain student-centered, active learning is definitely the place to begin inspiring students. By engaging students in the learning process, we can reach more student personalities and types, and hopefully all of them equally. As mentioned in the previous sections, one such set of equality measures involves the use of learning styles and other student personality inventories. With these inventories, our assessment uses the concept of learning styles and personality types as a foundation to not only design this particular active learning product but also assess it. The goal is to understand and encapsulate nearly all student preferences. There is without a doubt a need for more varied active learning products that use wide ranges of techniques, as well as a need for an innovative assessment methodology with dynamic and iterative student relationships.

When Felder investigated learning and teaching styles in engineering education during the late 1980s, there was quite a response from the field (Felder and Silverman 1988). Felder was attempting to explain common pitfalls in engineering classrooms and propose a plan to improve engineering education on a whole. Drawing on the research of Kolb, Myers, and even Piaget (Felder and Brent 2005), Felder looked to implement educational psychology research for his own practical purposes and for direct use in the classroom. He recognized divergences between the way most engineering students tend to learn and the way most professors tend to choose their teaching methods. As early as the 1990s, engineering educators found themselves deep in the throes of this new transition in understanding the old, traditional way of teaching engineering curriculum versus new, innovative possibilities. The traditional passive role of students is to be listeners during lectures. Any doing comes after class in the form of labs or homework. Felder later discusses these Changing Times and Paradigms (Felder 2004), considering active learning as the new frontier, pushing for "stimulating interactive lessons". Smith and Waller lay out New Paradigms for Engineering Education (Smith and Waller 1997), which include conducting assessments in various forms to summarize the impact of active learning methods.

When it comes to active learning, the art of teaching with the student in mind is at the heart of the matter. Smith (Smith, Sheppard et al. 2005) pinpoints the creativity involved in thinking about "How do you learn best?" and challenges educators to have more fun with curriculum and instruction. With a focus on a particular active learning strategy, called cooperative learning, we can think about how our finite element tutorials fit into the interactions present in the classroom. When it comes to evaluating if this pedagogy really works and is not just an educational fad, Prince reviews the research in terms of evidence proving active learning improves understanding (Prince 2004). No matter the magnitude of improvement levels, it is important to note that the overwhelming response to active learning studies is positive. In an international effort, Bernhard reports on the need for long-term results to be reviewed (Bernhard 2000). When computer science students were studied (Brenda Timmerman and Barnes 2003), increased comprehension and skills due to active learning techniques were reported. These students were thought to be the furthest from needing any form of active pedagogy, as they are often generalized as individualistic, introverted, non-social learners. Vallino goes on to discuss the need for active learning techniques, especially problem-based learning, in software development curriculum (Vallino 2003). With it, students reported better test scores and appreciation for the course. There are several efforts (Carlson and Sullivan 1999; Freuler, Fentiman et al. 2001) to implement "hands-on" engineering initiatives to discover the "excitement of learning by doing!" The state-of-the-art active learning involves personalized learning (Karagiannidis and Sampson 2004) where lessons are automatically adapted to fit students' individual learning style. "SMART" learning has been employed to develop intelligent distributed environments for active learning (Shang, Shi et al. 2001). The common thread throughout all these efforts is the focus on student-centered learning to improve education efforts.

Instructors across the country have made efforts to describe what improving engineering education means to them (Bjorklund and Colbeck 1999; Campbell 1999; Buxeda, Jimenez et al. 2001; Wood, Jensen et al. 2001; Froyd and Ohland 2005; Borrego 2007). To some, the focus is on problem-based learning, a particular type of active learning (Raucent 2001; Dym, Agogino et al. 2006). Even internationally (Berggren, Brodeur et al. 2003; Mills and Treagust 2003), initiatives have been made to redirect the focus of engineering instruction from the professor into the hands of the students. Felder's fourfold study on The Future of Engineering Education (Felder, Woods et al. 2000; Rugarcia, Felder et al. 2000; Stice, Felder et al. 2000; Woods, Felder et al. 2000) includes efforts to push for well-rounded engineers, for instruction that improves student learning, and for the criticality of applied engineering skills. Overall, the call for education reform in engineering focuses on active learning, integration of new technologies and teaching techniques, as well as a focus on faculty involvement in all efforts.

Wood and Jensen have collaborated on several "hands-on" efforts as well as the development and deployment of Active Learning Products (ALPs) to take the field of active learning in exciting new directions. Hands-on activities provide the opportunity for students of all learning styles and personality preferences to get actively involved with their learning and gain valuable experience useful in future industry work (Jensen, Wood et al. 2000; Jensen, Wood et al. 2003; Wood, Jensen et al. 2005). In terms of active learning exploration, the entire spectrum has been considered and the idea of incorporating MBTI data has been examined (Jensen, Wood et al. 1998; Linsey, Talley et al. 2007). Our latest collaboration includes the initial assessment development work (Kaufman, Wood et al. 2009). From this work, we created an innovative assessment algorithm that can be adapted to assess any active learning product. Additionally, this work highlighted preliminary results of active learning modules, in the form of tutorials, enhancing student learning of difficult course content.

The current state of assessing active learning in engineering education may hold the key to advancing efforts for reform. If we can further demonstrate that these new innovations in active learning are effective and within "arms reach," the growth of such efforts could be exponential. But we must look for authenticity in our assessment methods to determine if active learning efforts still under evaluation are positively affecting student learning. Without question, we are looking to determine if active learning programs are worthy of broader dissemination and continued evolution. It is imperative that the tutorials do not impact students in a negative way. In a study conducted at Colorado School of Mines (Olds, Moskal et al. 2005), we can learn the gamut of both assessment methodologies and experimental designs. From these comprehensive reports on current assessment methods being used, we can conclude that our novel assessment method is a hybrid meta-analysis of chosen focus groups, using a baseline data experiment for statistical analysis and equitability correlations.

Though similar efforts exist to develop appropriate assessment methods in support of active learning studies, few have pushed the limits on basic assessment methodologies. One innovative effort is from Stanford University, where Regan and Sheppard used Video Interaction Analysis (VIA) to study group performances during an experimental bike mechanical dissection exercise (Regan and Sheppard 1996). This type of assessment measure, using VIA technology, undoubtedly furthers the field because of its innovative nature.

With varied efforts to implement active learning into the engineering classroom, difficulty arises in successfully assessing if students are benefiting from the efforts to improve learning. In problem-based learning, especially that of a group structure, multifaceted rubrics may be necessary (Dahm, Newell et al. 2003). In Felder's Longitudinal Study of Engineering, the classic method of self-assessment is chosen, with intensive time and effort devoted to produce consequent comprehensive results (Felder, Forrest et al. 1993; Felder, Mohr et al. 1994; Felder 1995; Felder, Felder et al. 1995; Felder, Felder et al. 1998). We have found from our study that it is often possible to add in a supplementary self-assessment on behalf of the students (and even faculty), with the results being well worth the effort. Several other unique efforts (Piket-May, Chang et al. 1998; Davis, Gentili et al. 2002; Rhoads, Murphy et al. 2005) in assessing engineering education involve developing lab-intensive assessment methods, measuring gender parities, creating scoring scales for program improvement and accountability. According to the results reported in all the above studies, selection of an appropriate assessment methodology was not a trivial process, no matter the chosen assessment method. Educational efforts in general search for assessment methods that will "determine whether programs help the students they are designed to serve (Myers and Dynarski 2003)."

Further results of Felder's collaborations (Felder and Brent 2005), in addition to a useful online version of his learning style index, include a set of teaching techniques to help address all the learning styles present in any classroom. To date, Felder has continued his research in engineering education and the learning styles. Variables studied include success in introductory courses, rural versus urban backgrounds, and gender differences in student attitudes. Felder and his colleagues are mainly interested in student performance and retention. It is noteworthy that engineering industry is seeking more proficient graduates, but at faster graduation rates. The methods that have been researched in general, technical, and the psychology of education have proven to lead to more effective and efficient teaching (Felder and Brent 2001). In recent years, Felder participated in supporting several research studies (Felder, Felder et al. 2002; Zywno 2003; Felder and Spurlin 2005) to validate both learning styles and the Myers-Briggs Type Indicator to understand student differences to a further degree. Validation aside, there exist camps of educational researchers that resist the idea of learning styles (Cassidy 2004; Coffield, Moseley et al. 2009; Coffield, Moseley et al. 2009). Resistance and disagreement exist for several reasons, such as the lack of psychological studies that validate the actual existence of learning styles. And the cognitive science jury is still out. Even with varying opinions, there have been numerous efforts to use the concept of learning style to further understand how students differ, how educators can reach all students, and how to enhance learning (Felder and Brent 2005; Kolb and Kolb 2005; Hawk and Shah 2007).

What is important for us to note about Felder's history of research in the learning styles is where our research fits in. We may be using Felder's learning style index, but we combine it with Myers-Briggs Type Indicator, and take the research in an exciting new direction. We see that engineering education research has progressed in many varied and intriguing directions, but our research is breaking into a new sector of combining active learning with assessment measurements for equitability correlations. It is not trivial that we have chosen to use the Felder-Soloman learning styles and MBTI indicators. The overarching theme is the combination and extension of several useful active learning tools to develop our innovative tutorials and hybrid assessment method. Disagreement with the learning styles is accepted but arguably inconsequential for this work, and does not discredit the novelty of the active learning tutorials and assessment method in general. Currently, there are three 'Assessment of Student Achievement' projects being funded at CCLI, all varied in topics. One aims at developing a "Computerized Adaptive Dynamic Assessment of Problem-solving", another sets out to validate engagement measurements. Our study remains unique from what is being researched and executed in the classroom to date.

It is clear, that the global engineering community is discovering the potential of experiential learning environments and the corresponding need for effective assessment methods to determine intended quality and improvement of the learning process (Berggren, Brodeur et al. 2003). In order to expect institutions to accept the paradigm shift in engineering, educators supporting this reform must thoroughly assess their efforts in implementing active learning. We are looking to determine if these active learning modules have a positive effect on student learning by designing, implementing, and evaluating the tutorials based on active learning pedagogy. As we will see in the following section, the procedure of designing and developing the active learning module itself is very crucial. Another non-trivial step in this process involves choosing assessment methodologies properly. What we have learned from this overarching research review is threefold. First, our assessment method is a hybrid of sorts, combining quantitative statistical analysis with equitability correlations. This type of assessment method has not yet been tackled in the field and the potential is promising. Second, it is important to emphasize the choice of learning styles and personality preferences was motivated by resourcefulness. We view these learning style inventories and personality types as tools to consider all students, not a restrictive categorization limiting our views. Whether or not learning styles and MBTI are accepted, the key point is that our assessment method can be used with the equitability measure of an instructor's choosing. Third, we have chosen a basic content quiz to obtain our baseline data. An objective, multiple-choice quiz may be from older paradigms, but it serves our purpose with the baseline development of an active learning assessment method. Other content evaluation approaches may be adapted directly with our assessment method.

CHAPTER 3. RESEARCH FRAMEWORK

3.1 TUTORIALS AS ACTIVE LEARNING MODULES

A starting point for the objectives of this work is the development of the FE tutorials. Our main goal is to present the design, development, and assessment of one type of active learning modules, i.e. finite element (FE) tutorials. Student performance and enhanced learning are indicators of positive performance of the active learning products. Twelve FE tutorials were designed based on active learning pedagogy. After further development, they were tested in various classroom settings. Traditional lecture series in selected engineering courses were supplemented with these experiential active learning modules.

Based on this foundation, the following process is used to implement the learning modules. Participating students are given a content-based quiz to evaluate their baseline comprehension of historically difficult engineering topics. Then the finite element tutorials are administered and the quiz retaken. We are looking to determine, from a holistic viewpoint, if these active learning tutorials are accomplishing the goal of improving student learning. The tutorials assist in educating diverse undergraduate engineering students with a basic knowledge of FE theory, along with practical experience in applying commercial FE software to engineering problems. The idea is to improve both student comprehension and skill sets when it comes to content and analytical techniques that will be needed in later graduate or industry work.

To analyze the effectiveness of the learning modules, a level of improved understanding is calculated by relating quiz scores to improved learning.

Additionally, quiz scores are correlated to learning styles and personality types, followed by the application of basic statistical analysis. The end goal is to accurately and comprehensively assess the quality of the learning modules and whether they are equally serving students across different demographics. The following 12 FE learning modules are the focus of the initial assessment results:

Table 3.1: Finite Element Tutorial Development and Deployment

Tutorial Description	Area	Author	Software Selection
Curved Beam	Structural	Ashland Brown	COSMOSWorks
Stiffness	Structural	Ashland Brown	COSMOSWorks
Aluminum Plate	Heat Transfer	Ashland Brown	COSMOSWorks
Long Bar	Heat Transfer	Ashland Brown	COSMOSWorks
L-Bracket	Transient HT	Ashland Brown	COSMOSWorks
Biomedical	Biomedical	Paul Schimpf	Proprietary FE Code
Cylinder Drag	Fluid Dynamics	Essam Ibrahim	COSMOSWorks
Fluid Dynamics 2	Fluid Dynamics	Essam Ibrahim	COSMOSWorks
Probe Feed Patch Antenna	Electrodynamics	Vladimir Labay	Ansoft
Specific Absorption Rate	Electrodynamics	Vladimir Labay	Ansoft
Vibrational Plate	Vibrations	Chuan-C Chen	COSMOSWorks
Tapered Cantilever	Vibrations	Chuan-C Chen	COSMOSWorks

These twelve FE tutorials are the subject of this design and development section, as well as further analysis, results, and discussion sections.

3.2 FE TUTORIAL DESIGN

Each learning module is pedagogically rooted in active learning, as discussed in detail throughout Chapter 2. As an accompaniment to traditional lectures, the tutorials help guide students through active experimentation, concrete experiences, and reflective observation. The FE learning modules are designed for those students who have little to no experience using the FE analysis. Therefore, the basic nature of the problems makes it more likely that the students will grasp the correlations between the physical solution and the computational model. Each tutorial was developed in PowerPoint and is available in ppt and pdf file format, with a common template presented as follows:

- Module title, author, contact information, completion time, and references
- Table of contents
- Project educational objectives based on ABET Criteria (ABET 2006)
- Problem description
- Problem analysis objectives
- General steps and specific step-by-step analysis
- Viewing the results of the FE analysis
- Comparison of FE analysis to another technique
- Summary and discussion
- Background information on finite element theory

The steps to creating our 12 finite element learning modules [Table 3.1] can be explained using an exemplary learning module, the "Curved Beam" tutorial. The first task to tackle is selection of an appropriate commercial software package. The FE software available for consideration includes SolidWorks/COSMOSWorks, ANSOFT, MSC.Nastran, ANSYS, Algor, and the like. We are looking for the most straightforward selection with a gradual learning curve and internal supporting software help functions. Instead of choosing software they are most familiar with, instructors should consider student ease of use as the top priority. A supplementary educational goal of these tutorials is to learn the selected computer FE software. In terms of time, students should be able to learn the software code and construct problem models associated with the particular FE subject matter in under an hour, based on typical homework time. The steps should be easy to read and use. If possible, the software should be forgiving, or flexible. Common student errors could lead to impractical analysis. Adaptable software units can spot simple modeling mistakes and guide students through problem correction. This way, novice modelers are not penalized throughout the learning process. Together, these "help" programs can outline potential roadblocks, automate student assistance, and include internal tutorials.

For the "Curved Beam" learning module, the SolidWorks software was chosen. Besides meeting most of the considerations mentioned above, this software was attractive because participating students had introductory SolidWorks work in freshman graphics courses. For the curved beam machine design problem, the foundations were drawn from the literature, such as fundamentals from the well-known text Mechanical Engineering Design (Shigley, 8th edition). After initial testing, the problem could be solved by students using the tutorial in an average of 40 minutes. With most students spending 60 to 90 minutes on homework problems, this average met desired goals of the tutorial developers.

Educational objectives for the tutorial itself include providing students with a basic understanding of the finite element method, associated constraints and boundary conditions, methods of model verification, and experience with commercial FE software. In terms of common difficulties with the machine design problem, students have a hard time visualizing stress distributions in curved beams and calculating the radius of the neutral axis. Problem analysis objectives for the tutorials include assisting students in determining the stress distribution, using the FE method to verify this distribution, and using the FE method to verify the location of the radius of the neutral axis.

Ideally, each tutorial will take students through a step-by-step process similar to the following:

- ⇒ Overview of SolidWorks
    - o Left side of SolidWorks window
    - o Use of SolidWorks interface
    - o Toolbar explanation
    - o Tutorials and getting help
- ⇒ Verify SolidWorks is loaded on computer
    - o Open existing model in SolidWorks Simulation
    - o SolidWorks Simulation study folders
- ⇒ Creating SolidWorks model
    - o Setting the drawing units to inches
    - o Assigning material properties to model
    - o Applying constraints and boundary conditions to model
    - o Creating split-line force to model
- ⇒ Meshing the model and running the study

A snapshot of the "Curved Beam" FE Tutorial PowerPoint cover slide is shown in Figure 3.1. This exemplar approach and FE lerning module should provide a picture to have in mind while we continue to discuss each of the FE tutorials and their assessment.

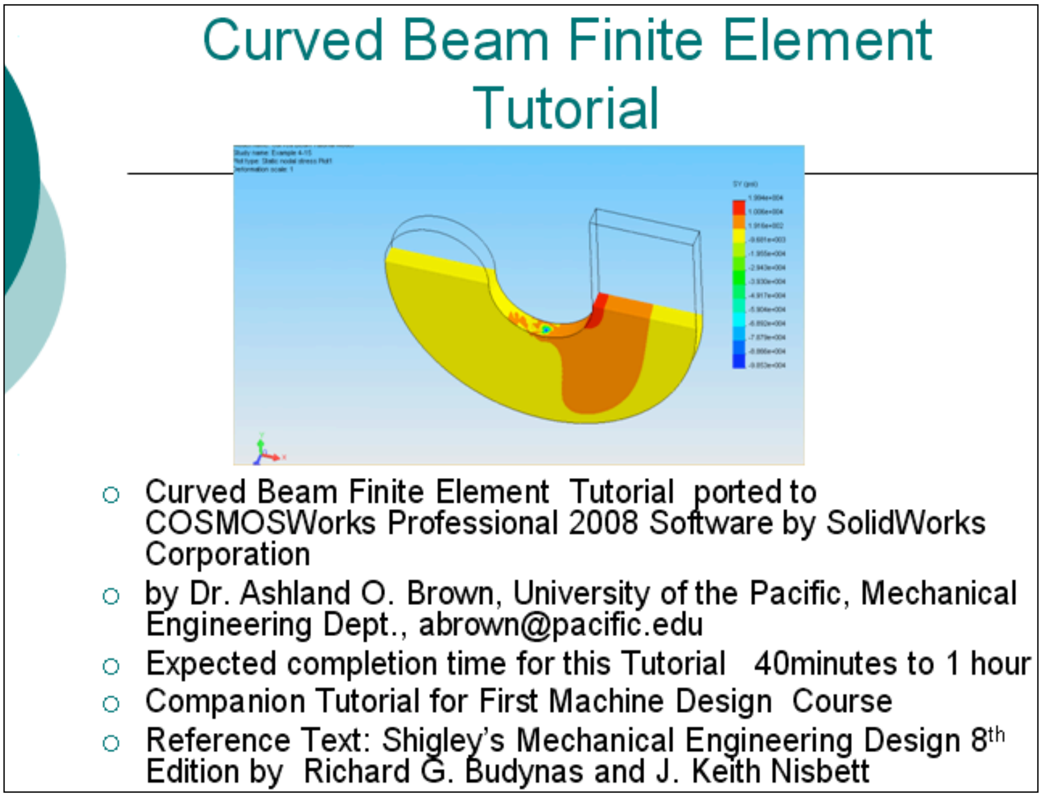


Figure 3.1: Snapshot cover slide

Students participating in the tutorial study start with the cover slide, then traverse through the experiential lesson. After the tutorial lesson is complete, the students take the content post-quiz and are administered the student survey. This survey [Figure 3.2] allows the students to give us their personal feedback about the active learning "activity". Also shown is an exemplary content quiz [Figure 3.3] the students take before the tutorial begins, and again after the lesson is complete.

The following is an example of a survey used, as discussed, for student feedback:

Student ID: _______

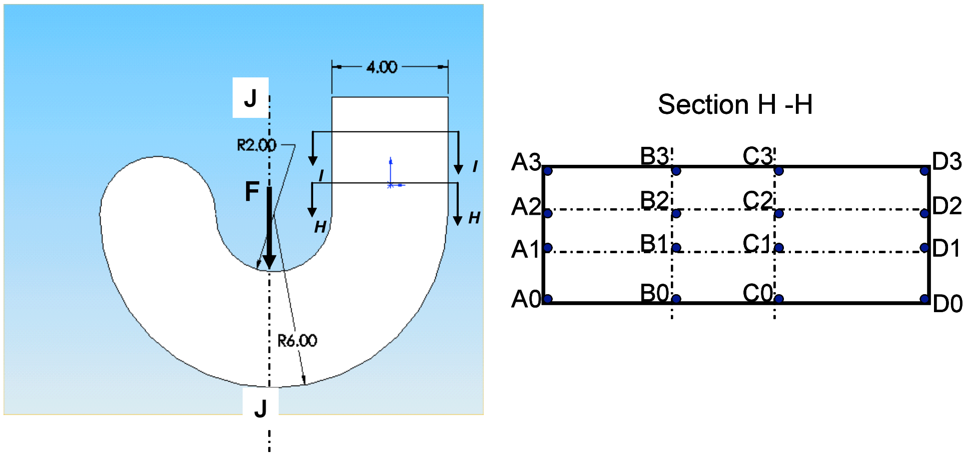
Please put an X in the box below that corresponds to your answer.

Question	**Disagree**	**Partly Disagree**	**Neither Agree nor Disagree**	**Partly Agree**	**Agree**
This activity helped me understand "curved-beam bending" in a conceptual manner.					
This activity helped me to understand the stress distribution in the curved beam.					
This activity helped me to visualize the stress distribution in the curved beam.					
This activity helped me to have a better understanding about the deformation of the curved beam under the concentrated load.					
This activity will help me to design a better curved beam to undertake a larger load.					
This activity helped to locate the points where the normal stress is zero.					
Activities like this one doesn't require full understanding of the finite element theory.					
This activity helped me to create a correct FE model from 3D CAD model for stress analysis.					
This activity helped me to learn how to apply the force, add constrains and create meshes for FE model.					
After completing this activity, I was able to implement a simple FE analysis using COSMOS.					
This activity was more effective than class time for lecture or board-work in terms of understanding the stress distribution.					
The FE analysis method is more useful and efficient to get all stress information for a structural member.					
I would like to learn more on using the finite element method to solve other mechanical engineering design problems.					
Totals					
Percentage of Students Selecting Response					

Figure 3.2: Sample student survey

The content quiz used for the "Curved Beam" Tutorial is as follows:

Student ID:_______________



Circle the best answer

1. The normal stresses at points at A0, A1, A2, and A3 are the same.
   a) True   b) False

2. The normal stresses at points at A0 and D0 have the relation as follows.
   a) $\sigma_{A0} > \sigma_{D0}$ b) $\sigma_{A0} < \sigma_{D0}$ c) $\sigma_{A0} = \sigma_{D0}$

3. The stress at the center of the cross section area is zero.
   a) True   b) False

4. The maximum normal stress occurs at the following sections:
   a) A0-A3 section b) D0-D3 section c) Both A0-A3 and D0 –D3 sections.

5. The shear stress at any point located on the cross-section A0-A3-D0-D3 is zero.
   a) True   b) False

6. The maximum stress on section A0-A3 is equal to its normal stress.
   a) True   b) False   c) The question doesn't make any sense.

7. The maximum shear stress occurs on section A0-A3.
   a) True   c) False   c) Both answer are wrong.

8. The stress distributions on Section H – H and Section I – I are the same.
   a) True   b) False

9. The stress level of the hook's left portion from section J – J is zero.
   a) True   b) False

Figure 3.3: Beam bending basic knowledge quiz

The next large step in the development process is the statistical analysis, discussed in the following chapter. Common empirical parameters are analyzed, e.g., mean, mode, median. More specifically, we are interested in determining if the “deltas” [(post-quiz score) minus (pre-quiz score)] are statistically distinct between pairs of learning styles and personality types. Using confidence intervals, the educational evaluator determines if there is any real statistical difference in how the FE tutorial is reaching individual students across demographic groups. For example, if an extroverted group has an average delta smaller than the introverts, confidence intervals measure the likelihood of a practical difference existing. These correlations act as feedback mechanisms in order to iteratively refine the tutorials with active learning still in mind. Ideally, students will be equitably active in the experiential lesson, independent of their unique sets of learning styles or personality preferences.

The on-line learning style and personality surveys return results indicating learning preference for the individual in each of the four categories and also includes a weight or strength for that preference (Felder and Soloman). These data allow one to differentiate, for example, between someone who is only slightly “active” over “reflective” in their learning style and someone who very strongly prefers an “active” to “reflective” learning environment. The average quiz scores and change in scores (deltas) are weighted using linear interpolation according to the weights reported from the corresponding learning style or personality survey for each student. The confidence intervals are calculated across the unweighted and weighted deltas.

The data we collected for this work is a part of the NSF funded CCLI project (Award Number 0536197) analogous with the FE tutorial development. Several universities assisted in implementing each tutorial in corresponding engineering classrooms. Professors were given previously developed tutorials along with other tools and then asked to return as much data as possible. The tools and data used in this work are discussed below.

The breadth of resources used throughout this assessment process covers most of the bases in terms of research standards. Professors traverse the assessment process by using the tools provided to produce data in return. Resources classified as tools include each of the finite element tutorials, the corresponding content quiz used for pre- and post-evaluation, student surveys, and the learning style and personality type index resources. We have chosen to use the Felder-Silverman index of learning styles, and the Myers-Briggs Type Indicator. Though MBTI varies slightly from strict personality types, we will differentiate between the two demographics simply as learning styles and personality types. Informal tools that emerged during the study include professor feedback and quiz validation. Data sets we are looking to study include results of pre- and post-quizzes, indices inventories, and survey responses. Specifically, the assessment work focuses on the results that correlate the quiz scores to learning styles and personality type. More generally, though, the global improvements in quiz scores can help us determine effectiveness of the tutorials as active learning tools in general.

The twelve FE active learning modules focused on in this work are a refreshing first step to filling a current void in engineering education. Their benefits, along with the assessment methodology developed in this work, have the potential to be far reaching.

CHAPTER 4. EQUITABILITY CORRELATION ASSESSMENT METHOD

4.1 ASSESSMENT FOUNDATIONS

Helpful steps for assessment of the FE tutorials are: (a) gathering student demographics (i.e. academic major, educational level, grade point average, expected grade earned in current course, reason for taking course, plans after graduation, age, ethnicity, and gender); (b) gathering Felder-Soloman learning styles and MBTI personality type (this analysis, along with learning objectives, can be reviewed and fed back into improving the learning modules); and (c) collecting all data and linking these data to a common student identification number for future evaluations and survey responses.

The next step is developing a measurement instrument for evaluating student learning directly associated with the active learning module. In this work, a multiple-choice quiz is used as the foundation for our baseline study. The content-based quiz is administered after the FE material is presented in class, but prior to introducing the student to an FE learning module. This ideally isolates enhanced student learning due to the tutorials alone. The tutorials supplement student learning of the difficult FE theories and methods, and associated engineering topic content. The same quiz is administered following the completion of the tutorial. The pre-quiz and post-quiz scores are again linked to the common student ID. In parallel, as soon as the student completes the FE learning module, an in-depth survey is administered to the students, providing the opportunity for much more open feedback to the assessment system.

4.2 ASSESSMENT ALGORITHM

In order to achieve the project assessment goals, an assessment methodology is fully developed [Figure 4.1]. To start, the active learning module, the FE tutorial in this case, is created. Before distributing the tutorial, however, an evaluation content quiz is created and the demographic data are gathered from the students. Once the pre-quiz is administered, the tutorial may be implemented. The post-quiz, identical in content to the pre-quiz, is taken after the tutorial. The students complete an in-depth survey when finished. The survey allows the student to be an active member in this iterative improvement cycle. Once all the demographic data and quiz scores have been linked with common student identification, the assessment process may move to the statistical analysis phase.

The next significant step in the assessment process is the statistical correlations. Once an evaluator decides upon a demographic group to study, the student quiz score results are grouped according to the chosen demographic. Common empirical parameters may be analyzed, e.g., mean, mode, median. Specifically, we are interested in determining if the deltas [(post-quiz score) minus (pre-quiz score)] are statistically distinct between pairs of learning styles and personality types. In order to perform this analysis, the data are treated as a sample of a theoretical larger population. Student-t distributions are used for the statistical analysis, as the sample sizes are relatively small for this study. Using confidence intervals, the educational evaluator determines if there are any real statistical differences in how the FE tutorial is reaching individual students across demographic groups. For example, if an extroverted group has an average delta smaller than the introverts, confidence intervals measure the likelihood of an actual difference existing.

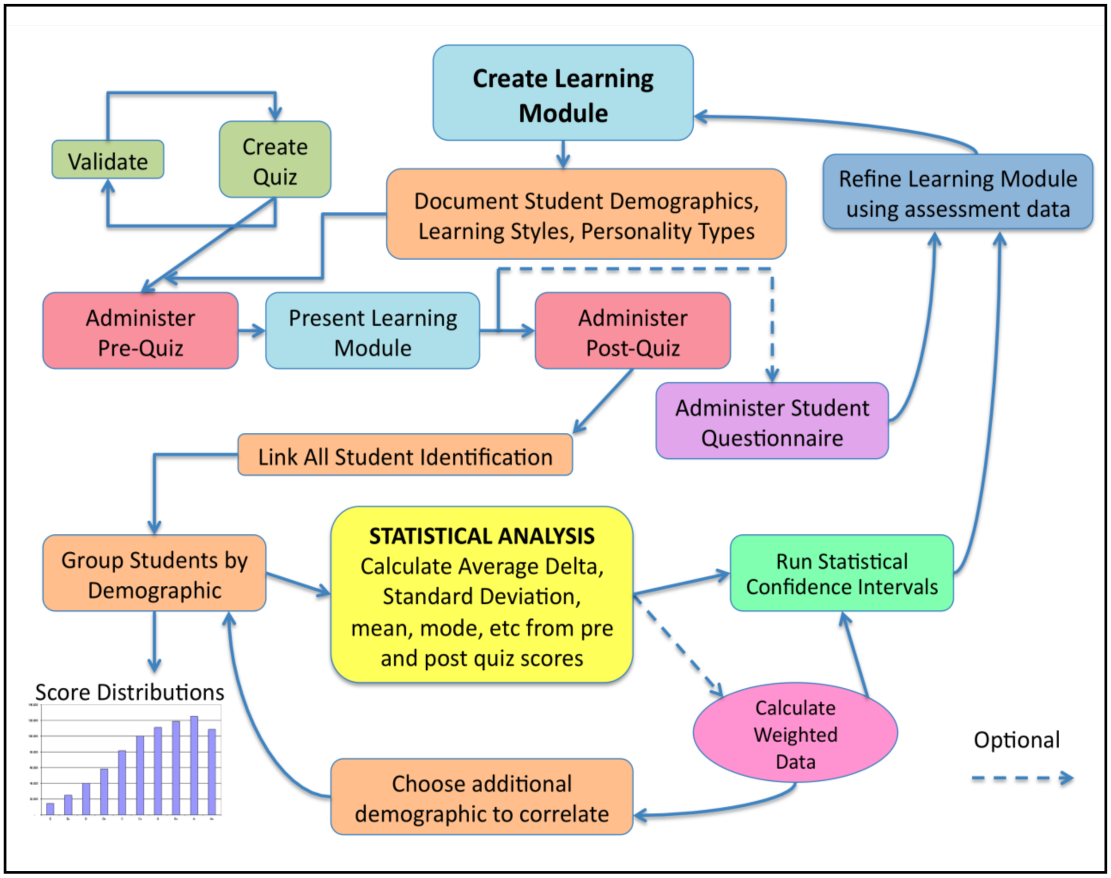


Figure 4.1: Equitability Correlations Assessment Method Algorithm

The on-line learning style and personality surveys return results indicating learning preferences for the individual in each of the four categories and also includes a weight or strength for that preference (Felder and Soloman ; Jung). These weights allow one to differentiate, for example, between someone who is only slightly "active" over "reflective" in their learning styles and someone who very strongly prefers an "active" to "reflective" learning environment. The average quiz scores and change in scores (deltas) are weighted using linear interpolation according to the weights reported from the corresponding learning style or personality results for each student. The confidence intervals are calculated across the unweighted and weighted deltas.

4.3 Assessment Results

The ECAM algorithm [Figure 4.1] is applied to four specific FE learning modules as representative examples from the set of tutorials developed as part of this work. Data for these modules include student demographics, learning styles, and personality types, in addition to student scores on pre- and post-quiz for each module. These four complete sets of data are used as the input to traverse the assessment algorithm in its entirety.

The assessment methodology seeks general trends in the statistical results. At a fundamental level, the quiz scores are assessed. Across all of the demographics, the pre- and post-quiz scores can be analyzed as a whole. If the entire group of students is improving in quiz scores, the FE tutorial has done its job well. The average of each group indicates an initial snapshot of the results, but only on a basic statistical distribution level.

The assessment algorithm is an iterative process, where the purpose is to continue reviewing the FE learning modules as more data are processed. Each level of evaluation, e.g. student demographics, learning styles, personality types, quiz scores, student surveys, and correlation statistics, should be fed back into the evaluation of the FE tutorial learning modules and the assessment itself. If one student group in the pair of a particular personality type or learning style is performing significantly better or worse than its counterpart, the tutorial should be reviewed and modified. The goal is to equitably improve learning across student groups. This performance variance is seen in a confidence interval over 50%, explained in detail next.

The confidence intervals represent the likelihood that the deltas for pairs of learning styles are statistically different. For example, a confidence interval of 75% for “active” vs. “reflective” learners indicates that there is a 75% likelihood that there is a real (statistically speaking) difference between the deltas for these two opposing learning styles. Although the confidence interval threshold of 95% is commonly used to indicate statistical significance, it may be informative to consider any occurrences where the confidence interval is greater than 50%. This would indicate that there was greater than 50% likelihood that one learning style benefited more than another from the FE learning module. The desirable result we are looking for is less than 50% chance that any one learning style or personality type is performing unequally to another.

The FE learning modules can be summarized into three broad categories of assessment: (1) Effectiveness in facilitating understanding of specific engineering knowledge and concepts; (2) Effectiveness in providing engineering students opportunities to apply commercial FE software to solve typical problems with the finite element method or finite volume method; and (3) Flexibility to meet the learning requirements of students with broad Learning Styles and MBTI Indices.

Chapter 5. Analysis and Results

5.1 An Overview of the Results

The results of the four exemplary FE learning modules are presented in the following manner. First, Tables 5.1 and 5.2 summarize the assessment results of the four tutorials comprehensively. These tables present the population size of each statistical group, the pre- and post-quiz averages of those demographics (both weighted and unweighted), and other statistically relevant data. The confidence intervals are also represented for each learning style and personality pairing.

Important table values include the deltas of each group's improvement as well as the associated standard deviation. The summative tables provide important insights into particular data sets and allow for easy comparison across subject, leaning style, and personality groups. The tables can be followed easily using the specific FE subject area color-coding. The separation of the color blocks follows the basic calculations of the quiz improvement and the student-t distribution confidence intervals. This division helps us answer two questions separately:

1. Are students improving their quiz scores after using the tutorial?
2. Are students improving equally across learning styles and personality types?

Results answering these two questions for each FE subject are discussed thoroughly in sections 5.2 to 5.5. A clear picture of the tutorials' total impact unfolds from the cumulative assessment results, as seen in the aforementioned tables and described through global assessment results in section 5.6 later in this chapter.

Table 5.1: Learning module assessment results across learning styles.

	Learning Style	N	Pre-quiz	Post-quiz	Delta	Stdev	Weighted Pre-quiz	Weighted Post-quiz	Weighted Delta
VIBRATIONS	Active	4	43.5	67.75	24.25	10.21	43.42	68.29	24.88
	Reflective	3	58.33	95.33	37	7.21	58.33	95.33	37
	Sensing	4	43.5	75	31.5	14.8	45.83	82.33	36.5
	Intuitive	3	58.33	85.67	27.33	2.08	62.71	89.86	27.14
	Sequential	1	71	100	29	-	71	100	29
	Global	6	46.33	76.17	29.83	11.79	43.13	74.17	31.03
CURVED BEAM	Active	10	46.6	61.1	14.5	12.0	47.6	60.7	13.0
	Reflective	4	69.0	78.0	9.0	9.0	86.7	89.7	3.0
	Sensing	8	47.1	61.1	14.0	13.6	43.3	58.4	15.1
	Intuitive	6	62.0	73.1	11.1	13.2	53.0	64.2	11.1
	Sequential	10	55.6	67.9	12.3	11.2	59.4	70.9	11.5
	Global	4	51.0	64.4	13.4	11.5	31.6	44.3	12.6
STRUCTURAL STIFFNESS	Active	6	61.7	68.3	6.7	10.33	63.7	69.0	5.3
	Reflective	5	54.0	56.0	2.0	14.83	48.5	58.5	10.0
	Sensing	7	58.6	61.4	2.9	12.54	59.3	60.7	1.3
	Intuitive	4	57.5	65.0	7.5	12.58	61.7	62.2	0.6
	Sequential	5	56	60	4	15.17	53.33	49.33	-4
	Global	6	60	65	5	10.49	64	67	3
HEAT TRANSFER	Active	6	61.9	61.9	0.0	12.8	60.2	60.2	0.0
	Reflective	4	67.9	71.4	3.6	18.0	80.6	77.6	-3.1
	Sensing	6	52.4	54.8	2.4	16.7	52.8	58.8	6.0
	Intuitive	4	82.1	82.1	0.0	11.7	85.1	81.2	-3.9
	Sequential	8	64.3	62.5	-1.8	11.9	61.0	60.4	-0.7
	Global	2	64.3	78.6	14.3	20.2	53.6	75.0	21.4

Average 30 Pt. Improvement

10 Pt. Difference

All > 10 Pts. Improvement

Reflective 5pt > Active

Sensing 1pt > Intuitive

Global 7pt > Sequential

Statistical Noise

~ 20 Pt. Improvement

Learning Styles	Unweighted CI (%)	Weighted CI (%)
Reflective vs. Active	87.5	86
Sensing vs. Intuitive	38.3	70
Global vs. Sequential	13	30.9

Learning Styles	Unweighted CI (%)	Weighted CI (%)
Active vs. Reflective	61.9	86.7
Sensing vs. Intuitive	30.1	40.9
Sequential vs. Global	12.3	12.8

Learning Styles	Unweighted CI (%)	Weighted CI (%)
Reflective vs. Active	42.6	42.6
Sensing vs. Intuitive	42.3	7.47
Global vs. Sequential	9.51	58.4

Learning Styles	Unweighted CI (%)	Weighted CI (%)
Active vs. Reflective	25.5	22
Sensing vs. Intuitive	20.2	69.6
Global vs. Sequential	52.4	62.2

Table 5.2: Learning module assessment results across MBTI types

Module	Personality Types	N	Pre-quiz	Post-quiz	Delta	Stdev	Weighted Pre-quiz	Weighted Post-quiz	Weighted Delta
VIBRATIONS	Extrovert	2	65.0	70.0	5.0	7.1	61.4	70.0	8.6
	Introvert	4	59.0	93.0	34.0	8.4	57.3	92.5	35.3
	Sensor	2	59	93	34	7.07	47.92	86.54	38.62
	INtuitor	4	49.5	82	32.5	7.94	49.24	80.18	30.94
	Thinker	2	50	85.5	35.5	10.61	43.54	72.12	28.58
	Feeler	4	54	85.75	31.75	6.08	59.03	89.04	30.01
	Judger	4	59	93	34	8.41	60.15	94.09	33.95
	Perceiver	2	40	71	31	4.24	39.62	71	31.38
CURVED BEAM	Extrovert	11	50.5	64.6	14.2	12.5	48.2	63.3	15.1
	Introvert	3	52.0	63.3	11.3	0.6	50.0	61.5	11.5
	Sensor	6	57.5	72.3	14.8	11.7	56.0	70.9	14.9
	INtuitor	7	47.6	57.1	9.6	7.6	43.8	53.6	9.8
	Thinker	10	49.9	63.4	13.5	12.8	47.3	61.4	14.1
	Feeler	4	53.0	66.8	13.8	5.5	51.0	66.1	15.1
STRUCTURAL STIFFNESS	Extrovert	9	55.6	60.0	4.4	13.33	54.6	61.0	6.5
	Introvert	2	70.0	75.0	5.0	7.07	75.9	77.9	2.1
	Sensor	6	63.3	66.7	3.3	10.33	63.5	71.4	7.9
	INtuitor	5	52.0	58.0	6.0	15.17	50.9	58.2	7.3
	Thinker	5	58	66	8	8.37	62.39	68.07	5.69
	Feeler	6	58.33	60	1.67	14.72	57.08	53.05	-4.03
HEAT TRANSFER	Extrovert	5	48.6	57.1	8.6	16.3	53.2	70.7	17.5
	Introvert	5	80.0	74.3	-5.7	7.8	82.8	75.6	-7.1
	Sensor	6	69.1	66.7	-2.4	10.8	66.0	63.7	-2.4
	INtuitor	4	57.1	64.3	7.1	18.4	71.6	78.3	6.7
	Thinker	5	68.6	62.9	-5.7	7.8	78.2	73.0	-5.2
	Feeler	5	60.0	68.6	8.6	16.3	56.7	70.5	13.8
	Judger	6	59.5	57.1	-2.4	10.8	53.4	47.8	-5.6
	Perceiver	4	71.4	78.6	7.1	18.4	79.2	77.9	-1.3

Average 30 Pt. Improvement

Personality Types	Unweighted CI (%)	Weighted CI (%)
Introvert vs. Extrovert	95.3	94.5
Sensor vs. INtuitor	16.4	64.8
Feeler vs. Thinker	27.6	11.1
Judger vs. Perceiver	39.8	34.7

10-15 Pt. Improvement

Personality Types	Unweighted CI (%)	Weighted CI (%)
Introvet vs. Extrovert	53.3	61.3
Intuitor vs. Sensor	63.7	60.5
Thinker vs. Feeler	3.9	15.2

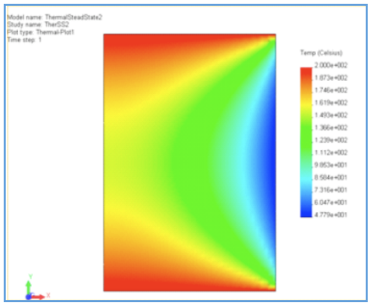
Extroverts & Thinkers Outperform Counterparts

Personality Types	Unweighted CI (%)	Weighted CI (%)
Extrovert vs. Introvert	5.91	42.02
Sensor vs. INtuitor	25.04	5.36
Thinker vs. Feeler	60.26	79.3

This module favors: Extroverts INtuitors Feelers & Perveivers

Personality Types	Unweighted CI (%)	Weighted CI (%)
Extrovert vs. Introvert	86.3	97.2
INtuitor vs. Sensor	59.6	57.3
Feeler vs. Thinker	86.3	93.5
Perceiver vs. Judger	59.6	30.3

5.2 Heat Transfer Analysis



The "Steady-state Heat Transfer in a Bar" FE tutorial reinforces the student's knowledge of expected heat transfer results under equilibrium analysis. An introduction to the use of FE heat transfer analysis software begins the tutorial. The FE method provides a comparison to the explicit two-dimensional finite difference method presented in most heat transfer texts.

An experimental group evaluates the Heat Transfer learning module and in this experimental set of data, all the students are visual learners. All personality types are represented in the correlation analysis. The ten students who participated in this learning module study and completed the learning style and personality tests were mostly senior engineering majors who were required to take the heat transfer course.

An overview of data from the heat transfer tutorial shows that five of the six learning style groups are not performing better or worse on the post-quiz when compared to the pre-quiz. The global learning group, however, definitely improves their overall FE heat transfer understanding by at least twenty points. When it comes to comparing the results of each pair of learning styles participating in the Heat Transfer tutorial, the story is more conclusive. As reported in the weighted delta column, the active learners and reflective learners perform basically the same. Their deltas both report little to no change between pre- and post-quiz averages and is confirmed with a 22% weighted confidence interval. Far below the 50% cutoff discussed, it can be confidently said that most likely the majority of the group is getting the same amount of help from the tutorial. The sensing learning style, however, is doing slightly better than their intuitive counterparts. The weighted confidence interval of 69% suggests that in this group the sensing students are likely learning more than the intuitive students. One interpretation is that the tutorial is written more towards sensing type learning and lacks equal weight of intuitive learning. Finally, the global learners are most likely outperforming the sequential learners with a 62% weighted confidence interval. The global learners are improving their quiz scores while the sequential learner scores stay the same.

The personality type results for the heat transfer tutorial indicate that two of the personality groups are evenly split 50/50, and two are 60/40. The pre-quiz scores have a much wider range of just below 50 up to 80. The post-quiz scores have almost the same range and deltas range from losing about 5% to gaining approximately 8%. In all four personality groups, one of the pairs seems to be doing worse on the quiz after the tutorial, compared to the counter pair. Reviewing the weighted delta, this learning module is conducive to extroverts, iNtuitors, feelers, and perceivers.

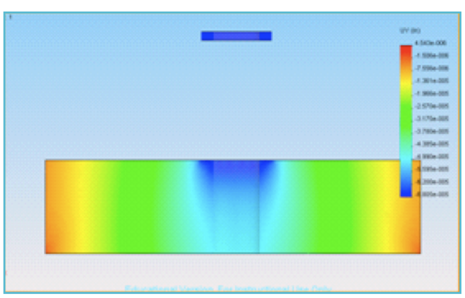
In all four cases, the tutorial appears to be biased towards one side of the personality in both unweighted and weighted confidence intervals. There is a large spread in the weighted data, a 97% confidence interval across the extrovert versus introvert group. The tutorial is likely to be very biased towards extroverts because extroverts improved their quiz scores and introverts' scores went down. In the next group, the intuitors are gaining more from the tutorial, but the spread is not as wide, just a 57% confidence interval. Again, the thinker versus feeler spread is quite large, with a 94% confidence interval biased towards feelers. The last group, judgers and perceivers, have an unweighted confidence interval around 60%, but only 30% when the data is weighted. Whether or not this implies a bias towards perceivers, it is more significant that both groups are not improving after the tutorial.

The insights gained from this analysis are twofold, in concurrence with the goals of assessing the learning module for overall educational benefit and for equality across all learning style and personality type groups:

- The tutorial needs to be significantly advanced to improve student learning, as seen with a minimum improvement of 10 points on the quiz
- The tutorial is geared towards certain learning styles and personalities in most cases and should be adjusted to include all groups equally in the active learning process.

Based on the first results, the second claim is not conclusive or definite since the learning module does not significantly provide for student improvements in learning. Once the tutorial is improved for learning, equitability should be reassessed and adjusted from there.

5.3 Stiffness Analysis



The "Bolt and Plate Stiffness" FE tutorial bolsters the student's knowledge of structural stiffness concepts in bolted joint connections. Introduced to the FE software, the student can predict bolted joint stiffness for plates. Pictorially, the stiffness field in a plate under a bolt can be reviewed.

For the sample experimental group in this learning module, the same visual versus verbal learning style correlation is missing as with the heat transfer assessment. In addition, the judger/perceiver personality type could not be analyzed for this set of data. All of the students are perceivers in this case. The total number of students involved in this study was 11, all senior mechanical engineering students.

Quiz results are presented across the learning groups for the Stiffness tutorial. The raw delta scores show a slightly positive trend. All of the learning styles improve between 2 and 7.5 points on the quiz. The standard deviations range between 10 and 15 points. Once the data is weighted, we see that the reflective group performed 5 points better than the active; sensing less than 1 point better than intuitive; and global 7 points better than sequential.

We cannot tell initially if the differences in deltas, either weighted or unweighted, statistically mean the groups are likely to be performing differently. Taking the deltas, standard deviations, and corresponding group sample sizes into account, data indicate the raw delta results for this tutorial do not imply statistical difference. All of the unweighted confidence intervals fall under the 50% cutoff, so the groups are likely to be performing equally. Similarly, the weighted confidence intervals are small, with the exception of the 58% result for global versus sequential. Overall, this tutorial shows student performance equally across the three learning styles pairs involved, but is slightly favoring global learners over sequential learners.

The same eleven students provide a similar story when it comes to personality types. The range of deltas is between losing 4 points and gaining 8. The standard deviations are up to 15 points again. Just considering deltas, the extroverts and thinkers outperformed their counterparts on the post-quiz. The confidence intervals need to be considered to determine if these differences are significant or not.

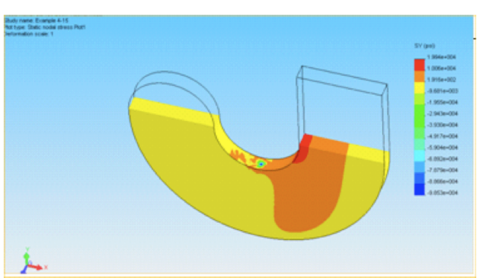
Both the extrovert versus introvert and sensor versus intuitor groups resulted in confidence intervals far below 50%, implying the students are most likely learning equally across their personality types. The 60% and nearly 80% unweighted and weighted confidence intervals suggest that thinker personality types are more likely benefiting more than feeler personalities.

For the stiffness tutorial, the learning module is helping students learn equally across the majority of learning styles and personality types. The overall assistance level needs to be improved; however, as no group performed over ten points higher on the quiz after using the tutorial. Furthermore the following two statements can be made:

- The tutorial is improving student learning, but not to the degree we desire.
- The tutorial is reaching the majority of groups equally, with the exception of a slight bias towards thinkers in the thinker-feeler personality pairing.

Similar to the previous tutorial, the overall learning needs to be improved and equality reassessed after those improvements. This pattern of results suggests that answering each question on overall learning and equitable learning individually results in dual feedbacks into both areas of improvements. When either result suggests changes need to be made, both questions need to be assessed again after adjustments, hopefully with improvements being made.

5.4 CURVED BEAM ANALYSIS



The "Curved Beam" FE tutorial tests student understanding of stress distributions in a curved hook using the FE software. To verify the stress distribution, the student determines the neutral axis of the curved beam numerically and graphically.

For this experimental group, the set of data show the same trends as for the Stiffness learning module all the students are visual and perceiving. The student group size increased to 14 in total for this senior machine design course.

The 14 students are distributed in various combinations for learning style groups, but all the quiz averages are weighted with corresponding indices from the student learning style types. We can see that five out of the six groups perform over ten points higher on the quiz as a result of using the FE learning module. The only pair that shows any real difference in quiz performance is the active learners over reflective learners, receiving ten more points in weighted delta terms.

In the Curved Beam module data analysis, the unweighted and weighted confidence intervals for the first pair demonstrate there is between a 62% and 87% chance that the reflective learners benefit statistically different than the active learners. The last two learning style pairs benefit equally, resulting in an 11 to 15 point gain from the learning module.

All of the personality types perform better on their post-quizzes after using the Curved Beam learning module. The improvement range is between 10 to 15 points.

Improvements needed on the Curved Beam tutorial can be in reaction to two personality pairs that show weighted confidence intervals of about 60% suggesting some equality needs to be added across the extrovert versus introvert group, and the sensor versus intuitor group.

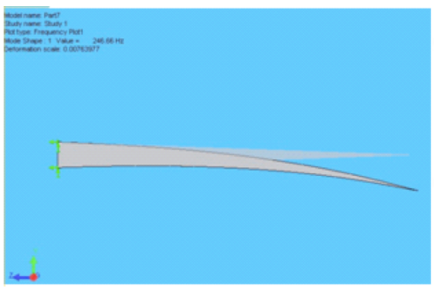
Overall, the Curved Beam FE tutorial gives us an example of highly positive results from learning module assessments:

- An average improvement of at least 10 points between the pre- and post-quiz

- Most of the confidence intervals are below 50%, implying the learning style and personality type groups are most likely performing equally with the tutorial.

Together, these results suggest this learning module is effectively reaching most students.

5.5 VIBRATION ANALYSIS



"Lateral Vibration of Tapered Cantilever" is a FE tutorial that takes the student through concepts including natural frequency and vibration modes in a non-uniform cantilever beam analysis. The student is introduced to the FE method by determining the beam mode shapes at resonance frequencies. With the software, these findings can be graphically verified.

For the experimental group, the final set of data includes seven senior engineering students, spread across all four personality types. The visual versus verbal learner pair is again absent from this experimental group due to lack of difference in preference.

The learning style correlations for this Vibrations module represent an average quiz score improvement of approximately 30 points. Coupled with an average standard deviation of about 10, this suggests the particular tutorial used for this learning module is very effective in assisting students learn. Some groups may be outperforming their counterparts, as seen through confidence intervals, but overall this learning module is outperforming the three previous tutorials discussed.

The following groups are most likely learning unequally across learning styles: reflective may be getting more from the tutorial than active learners and sensors are performing statistically better than intuitors. These confidence intervals around 70% to 80% tell us we need to improve the learning style equality across all the learning styles.

All but the extroverted personality types are gaining an extra 30 points of knowledge on the quiz due to the Vibrations learning module. The 95% confidence interval for the introverts versus extroverts shows, with high likelihood, the introverts are learning statistically better than the extroverts. This tutorial is geared towards introverts and should be revised to assist extroverted learning equally.

In the end, this Vibrations learning module presents positive results. It is evident that:

- The tutorial helps students improve their quiz over 10 points, up to 30 points.
- The equitability correlations give us initial feedback on how to improve the learning experience for all students, no matter their preferred learning style or personality type.

This first result is very promising; the FE tutorials have a chance to really improve student learning, potentially improving student scores from the failing range to above passing. This should be a new standard for each learning module implemented to be measured against.

5.6 Global Assessment

Returning to all 12 FE learning modules, the global assessment results consider the performance of the tutorials as active learning modules in general. The quiz results are not analyzed according to specific student demographics, but analyzed for overall improvement in each course due to the tutorials. This general analysis is much more straightforward and very telling. The results display the number of students involved in each tutorial study, their average pre- and post-quiz scores, the associated delta improvement, and the percentage improvement. From these quantitative results, we can analyze our research work holistically by answering the question: Are these 12 FE learning modules enhancing student learning of difficult course content material as well as FE theory?

The motivation behind this global assessment strategy is to step back from the ECAM results and take a larger snapshot of the tutorials. While the ECAM results and analysis can display how each tutorial is performing in terms of student learning styles and personality preferences, the big picture can provide additional and complementary insights. Specific results discussed in the previous section are particular to one individual learning style or MBTI pair, but what can we say about the tutorials as active learning products across all students as a group? We want to assess if the intended active learning experience has a positive effect on student learning in general.

Table 5.3 addresses the overall assessment goal of determining if these tutorials are effective at improving learning. These sets of data can be looked at very methodically. First, we have 12 total tutorials to assess, each with unique subject matter from structural engineering to electrical engineering. Then, we can see how many students participated in the tutorial pilot study. Almost 150 students participated in the first round of each FE learning module implementation into the classroom setting. An average of 12 students were in each class using the tutorial to supplement the curriculum. For each tutorial, we can see the average pre-quiz score for the groups of students, ranging from 42% correct to 71%. The overall average of all pre-quiz scores pertaining to all 12 FE tutorials was 58.6%, well below passing.

We can see the overall post-quiz average of 75.5% demonstrates a statistically significant and marked increase in performance, with an individual range on the 12 tutorials of 65% to 82% correct. What this tells us is that on average, students are not passing the content pre-quiz, but after being administered the tutorial, the average student improves their post-quiz score to above passing. On a strictly percentage base improvement scale, it becomes clear that there is an average delta of almost 17 raw percentage points. This can be directly translated as grade enhancement of a letter grade and a half. If we consider the improvement on a relative percentage bases, there is an average improvement of 30%. For example, on the Microstrip Antenna Design tutorial, scores improve from an average of 60 to over 80, corresponding to an improvement of 35.5%. The range of percentage improvements starts at about 15% and goes up to nearly 60% improvement.

Table 5.3: Cumulative Global Results of FE Tutorials

FE Learning Module Subject		**Students**	**Pre-Quiz Avg**	**Post-Quiz Avg**	**Delta**	**Percentage**
Curved Beam Structual Analysis		9	71.1	82.2	11.1	15.6%
Stitffness Bolt Structual Analysis		12	55.8	65.0	9.2	16.4%
Long Bar Heat Transfer		19	63.1	72.9	9.8	15.5%
L-Bracket Transient Heat Transfer		19	63.1	72.9	9.8	15.5%
Biomedical Electromagnetics		6	50.0	76.7	26.7	53.3%
Fluid Dynamics Cylinder Drag		7	62.9	77.1	14.3	22.7%
Fluid Dynamics Friction Flow		7	62.9	77.1	14.3	22.7%
Vibration of Cantilever Beam		7	49.9	79.6	29.7	59.6%
Vibration of Tapered Beam		16	58.0	72.3	14.3	24.6%
Microstrip Antenna Design		10	60.0	81.3	21.3	35.5%
Sar Analysis		20	63.8	81.5	17.7	27.7%
2D Transmission Lines		10	42.5	67.5	25.0	58.8%
Total	:	142				
AVERAGES	**:**	**11.83**	**58.6**	**75.5**	**16.9**	**30.7%**

These cumulative results allow us to take a global perspective on the effectiveness of the tutorials. As active learning products, we asked if these particular tutorials were enhancing student learning. From these initial results, we make a number of conclusions:

1. On average, the tutorials assist students learning the material with about a 30% improvement to content knowledge,
2. Student quiz scores improve from below passing to above passing by almost two letter grades on average, and
3. The tutorials have been piloted in 12 unique classrooms. With even one iteration of refinement, the potential opportunity for improved learning is indicated and exciting.

These results, as well as the total results from this entire chapter are further discussed in the following chapter.

CHAPTER 6. DISCUSSION AND INVENTION

6.1 ECAM DISCUSSION

As a result of the work to date, there is much to garner from the demographic correlations of the FE learning modules. First, the tutorials are helpful as complementary lessons to topics in challenging engineering courses. They are also, at a basic level, assisting students in being introduced to the real-world finite element method. The assessment results for the exemplary learning modules demonstrate these findings, but they also show that the development of tutorials is not a trivial process. It is possible for tutorials to not add significantly to the learning of challenging material or to bias certain student groups over others. These possibilities underscore the need for appropriate and continual assessment feedback of the learning modules as they are created and advanced.

The tutorials developed in this project form a foundation and starting point for introducing FE across engineering curricula. The associated assessment methodology provides for continuous, open feedback and improvement. This crucial FE material, which is used in practical engineering everyday, is expressed in a unique way. These tutorials can be quickly accessed and updated (for example via the web), speeding up the optimization process to a desirable degree. This process mirrors that of FE commercial software updates used by engineering firms and the instantaneous training that employees take to solve engineering problems.

An important engineering education lesson can be harvested from the learning modules and their assessment: a single assessment strategy can answer educational value questions and demographic equality questions at the same time. These two goals, for students to not only learn well but also to learn independent of their demographics and personality types, are often kept separate and analyzed by distinctive efforts. The data shows that these two educational goals are not mutually exclusive. If an educator focuses on developing an active learning module that reaches the spectrum of learning styles and personality types, and allows for short-term evaluation and feedback, the learning module can be reviewed and improved before the next set of students use it. This assessment methodology goes beyond basic evaluation by correlating learning style and personality type pairs to their performance. No matter how the assessment technique is adapted to fit a unique learning tool, each level of evaluation along the way can be fed back into beneficial results for learning. The system feeds itself for continual improvement and can be a model for application to many other forms of engineering educational evaluations.

From this initial study of FE tutorials, a foundation is established for assessing the effect of active learning modules. A three-stage evaluation process forms the groundwork:

1. Educational Evaluation: Are the tutorials improving student learning?
2. Equality Correlation Study: Do the learning modules help all students learn independent of their demographics, learning styles and personality types?
3. Fundamental assessment techniques of active learning: How can the learning modules and assessment methods be iteratively and continually improved to benefit engineering education on a whole?

The ECAM work set out to assess the equality of the FE learning modules. A fundamental contribution from this effort is an exciting new active learning assessment methodology for the engineering education community.

6.2 ACTIVE LEARNING DISCUSSION

Active learning provides future engineers with the opportunity to be more involved in their own education. Active learning techniques and products allow students to practice and apply what they learn in lectures and from textbooks, and in a hands-on and inspiring manner. To date, 12 Finite Element learning modules have been designed and developed with active learning pedagogy foundations to supplement already challenging engineering curricula. The goal is to not only improve student learning of the established content, but also introduce important finite element commercial software and applications. By furthering the understanding of class content, students can focus on learning methods they will need in engineering industry or advanced graduate studies.

Our initial efforts for this work set out to determine if we can develop an effective assessment tool to validate these tutorials as active learning products. In the process, an innovative assessment method was developed to judge if the tutorials are benefitting students across learning styles and personality types. But the question still remains: How well are these tutorials performing as active learning modules? After our initial run of the analysis, we can tell student learning is being enhanced by the tutorials. The student averages for content pre- and post-quiz scores give us clear results. Upon completing their traditional coursework, students are administered the tutorial and quiz sequence, after which we are able to gather baseline data for how well they understood course content. With the supplementary tutorials, students not only understand the course content better, they have newfound experience with the practical finite element method.

After the design and development process, the active learning pedagogy cannot be forgotten. Assessment and further improvement is based on the active learning foundations originally considered. The cumulative results display average improvements of nearly two raw letter grades. An alternative view is to consider the average 30% improvement. The basic story is that most students are failing content quizzes before the tutorials and passing content quizzes after taking the tutorials. In the end, the design and development continues. Iterative assessment feedback enables us to continue improving student learning. Overall, the global results reveal positive trends of these initial active learning tutorials enhancing student learning.

6.3 INVENTION

A supplementary product developed in conjunction with this work includes two specific tools for educators interested in implementing active learning tools in the classroom. We are looking to pass along some of the important lessons learned throughout this work. By following certain steps, one can be sure to design, develop, implement, and assess active learning products to the benefit of all students. By seriously implementing active learning pedagogies, educators can come one step closer to enhancing student learning across all demographics.

The first product is an ECAM Roadmap to guide educators through implementing and assessing the active learning product of their choosing.

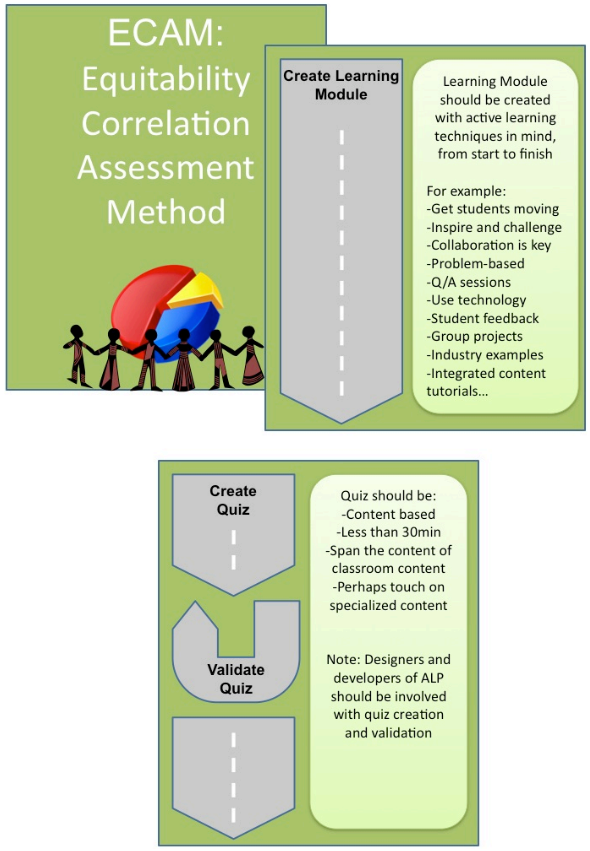


Figure 6.1: ECAM Roadmap Development

This roadmap builds on the original algorithm designed for the ECAM, but breaks down each step into destinations along a journey. Educators can keep this handy foldable map packet on their desk to understand the active learning assessment process. The following figure explains how the previous roadmap entries fold all together into the ECAM roadmap:

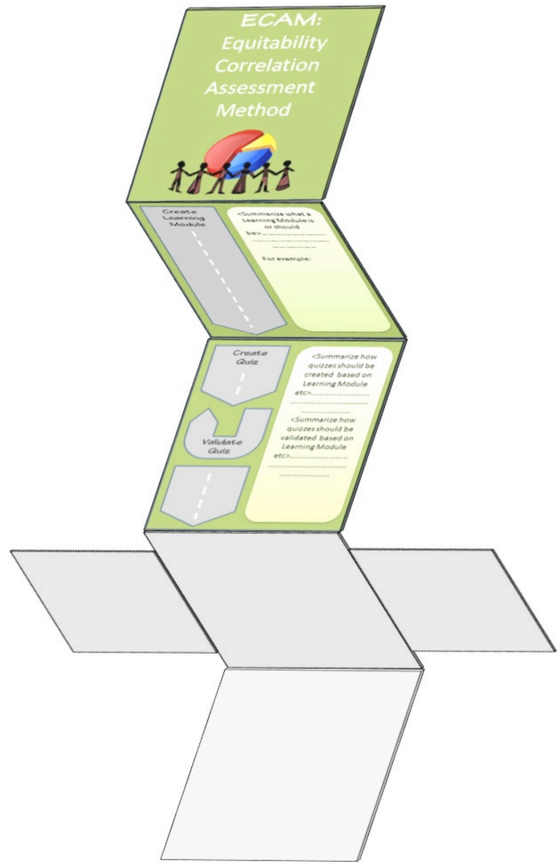


Figure 6.2: ECAM Foldable Roadmap

The following diagram explains the logistical design of our ECAM Roadmap:

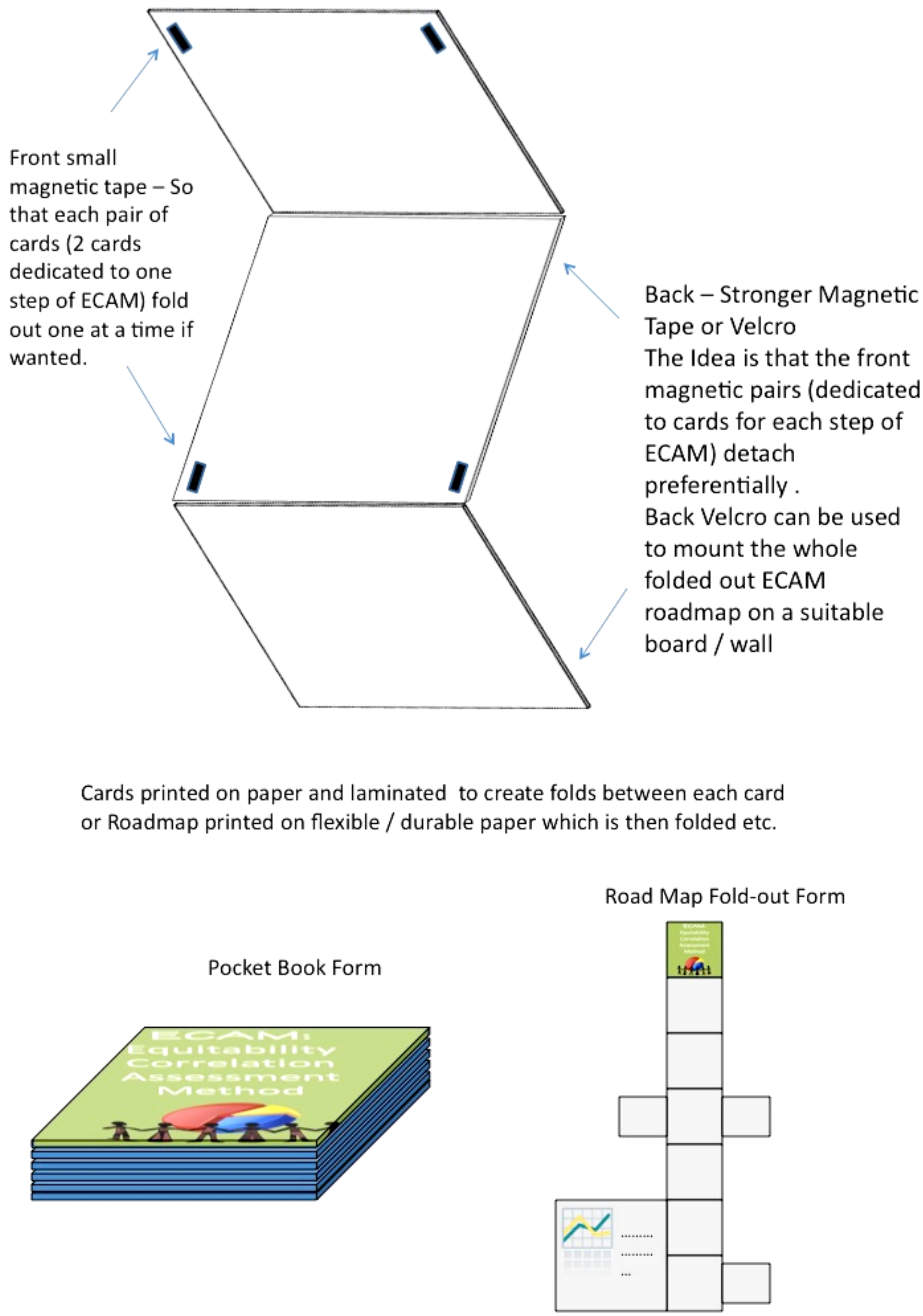


Figure 6.3: Logistics of ECAM Roadmap

Chapter 7. Conclusion and Future Work

Learning modules, in the form of tutorials, form the basis of our work in developing finite element techniques to support systemic engineering principles. Our initial results show that the development of tutorials is challenging and significant. However, these results also show that tutorials can have a tremendous benefit to student learning across a range of student groups.

The design of these unique active learning products combines the difficulty of finite element analysis theory with the practical hands-on experiential lesson, enhancing student learning in various regards. This groundbreaking study provides a unique opportunity to pilot both the tutorials and assessment method in the classroom. The cumulative results of all 12 finite element tutorials were not only positive but also informative. From the equitability correlations, we can find the areas of improvement for future iterations of particular tutorials. On the whole, the average improvement to student learning directly related to these active learning tutorials is well over acceptable. As active learning tools, these tutorials are providing students with the chance to go from below passing on content quizzes to above passing. With the iterative assessment method, the potential to refine and improve each tutorial will only further active student learning.

At the core of learning module development is the ability to assess the impact on learning. We have developed an assessment strategy targeted for tutorials, but which also generalizes across active learning methods. This exploratory new technique of assessing active learning has the potential to advance engineering education. By measuring students' abilities across learning styles and personality types, the equity of the learning modules may be assessed, as well as their impact in an engineering content area.

The next step for this research effort is to directly revise and refine the 12 FE tutorials based on these results. Though iterations of the experiential activity have occurred in several classrooms, we need to take the time to improve each tutorial to equitably enhance the learning of all potential students. We have the data analysis suggesting the needed improvements; all that is left to do is return to the active learning pedagogies and creatively redesign certain aspects of the tutorials. Overall, the results have proven students can go from a fairly low-level performance level to a much higher proficiency with the subject matter. Our final active learning tutorial had the potential to take failing students to the highest grade levels; it is just a matter of enhancing our original efforts with continued iterative refinement and improvement.

In the future, this work will undoubtedly continue to develop and improve. With these initial positive results, not only can we consider developing entirely new tutorials in further subject areas and fields, but we can also continue to improve the existing ones. The twelve FE tutorials researched in this thesis have the potential to positively impact many more students. With continued support, partners in this research can implement these tutorials in classrooms across the country. To further the enhancement of student learning, the tutorials need to be administered to more students. This way, we can carry on the ECAM with new students and instructors feeding into iterative refinement of each and every tutorial. With these growing efforts, the Engineering Education community can continue to design and implement active learning products in the classroom.

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